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(71) Applicant(s)
**Oxford Instruments (UK) Limited**
**(Incorporated in the United Kingdom)**
**Old Station Way, Eynsham, WITNEY, Oxon, OX8 1TL, United Kingdom**


(72) Inventor(s)
**Robert Andrew Slade**
**Jonathan Cole**
**Peter Hanley**


(74) Agent and/or Address for Service
**Gill Jennings & Every**
**Broadgate House, 7 Eldon Street, LONDON, EC2M 7LH, United Kingdom**

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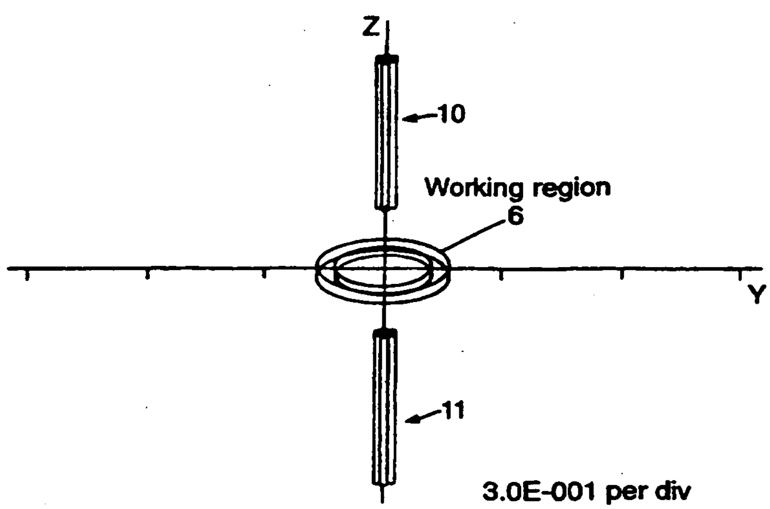
(54) Abstract Title
**An NMR well logging magnet using high-temperature superconductors**


(57) A magnet for NMR well logging comprises two opposed sets 10,11 of elongate, parallel and abutting HTSC coils. The magnet produces a uniform field in an external working region 6. The position of the working region may be altered, for example by displacement to one side of the magnet (figure 2), by adjustment of the gaps between opposed coil pairs and adjustment of coil lengths. The magnet may also be applied to medical imaging and to spectroscopy. The fields of the two sets may be opposed or aligned.


Fig.7.

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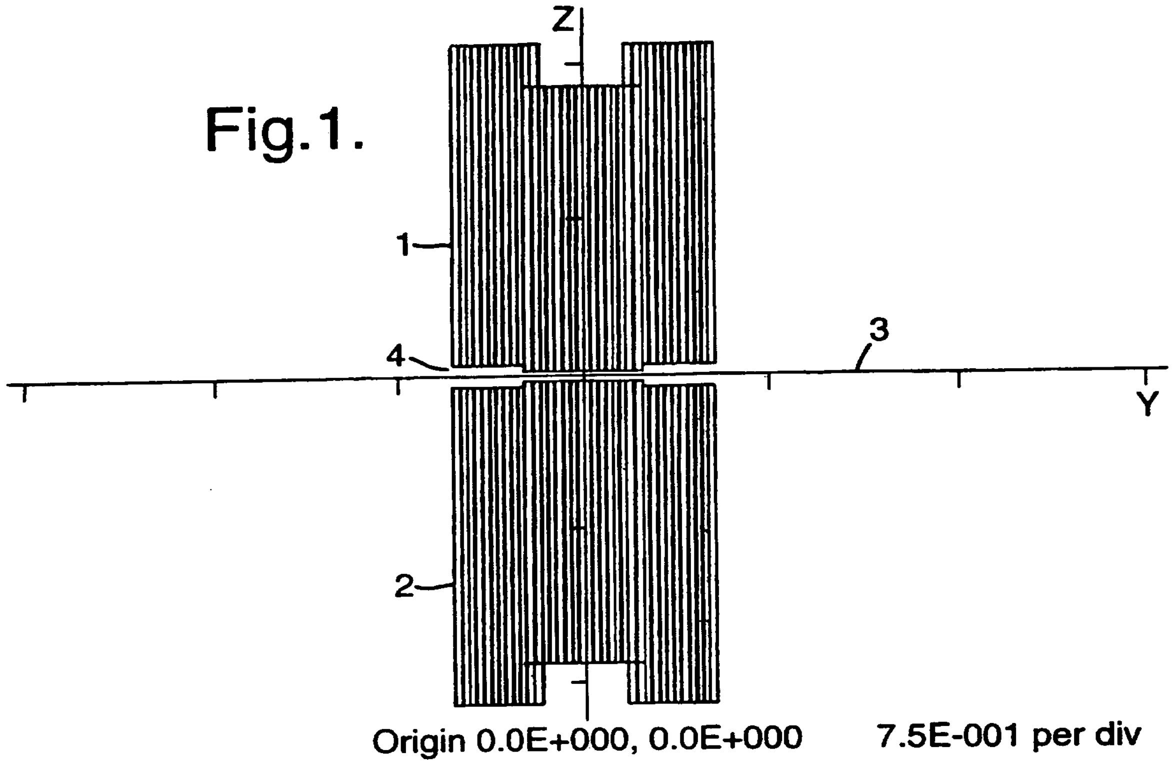

Z
1
2
3
4
Y
Origin 0.0E+000, 0.0E+000
7.5E-001 per div

Fig.1.

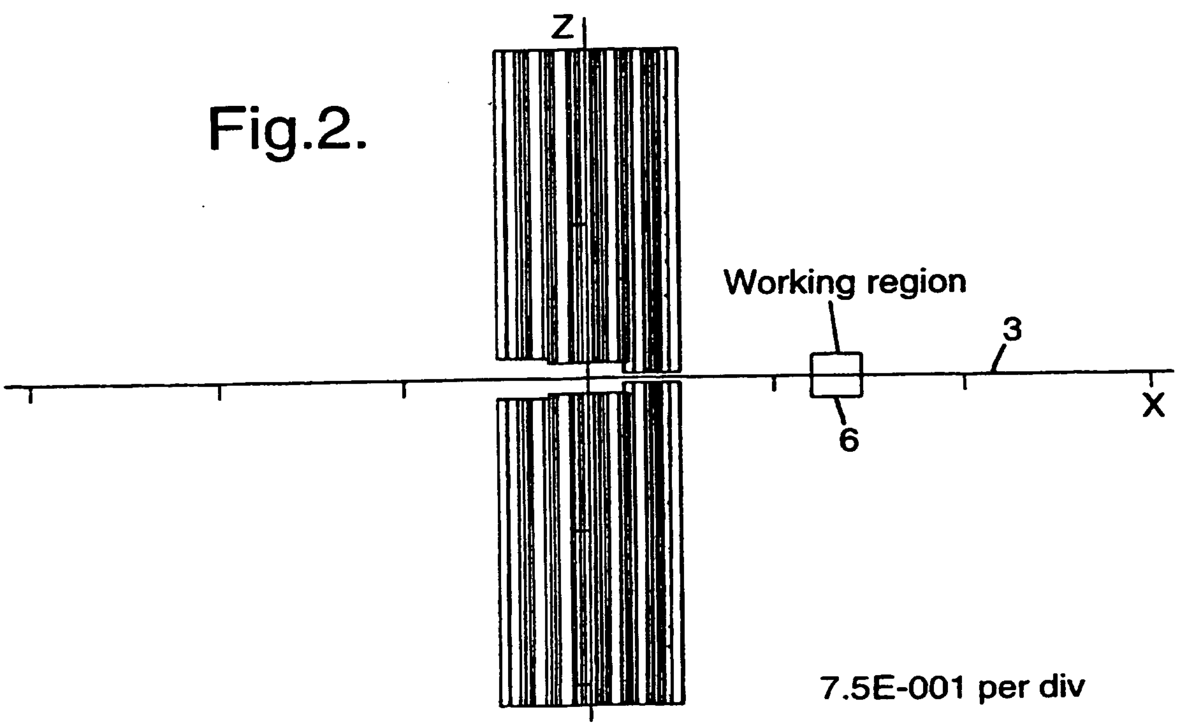

Z
Working region
3
6
X
7.5E-001 per div

Fig.2.

Fig.3.

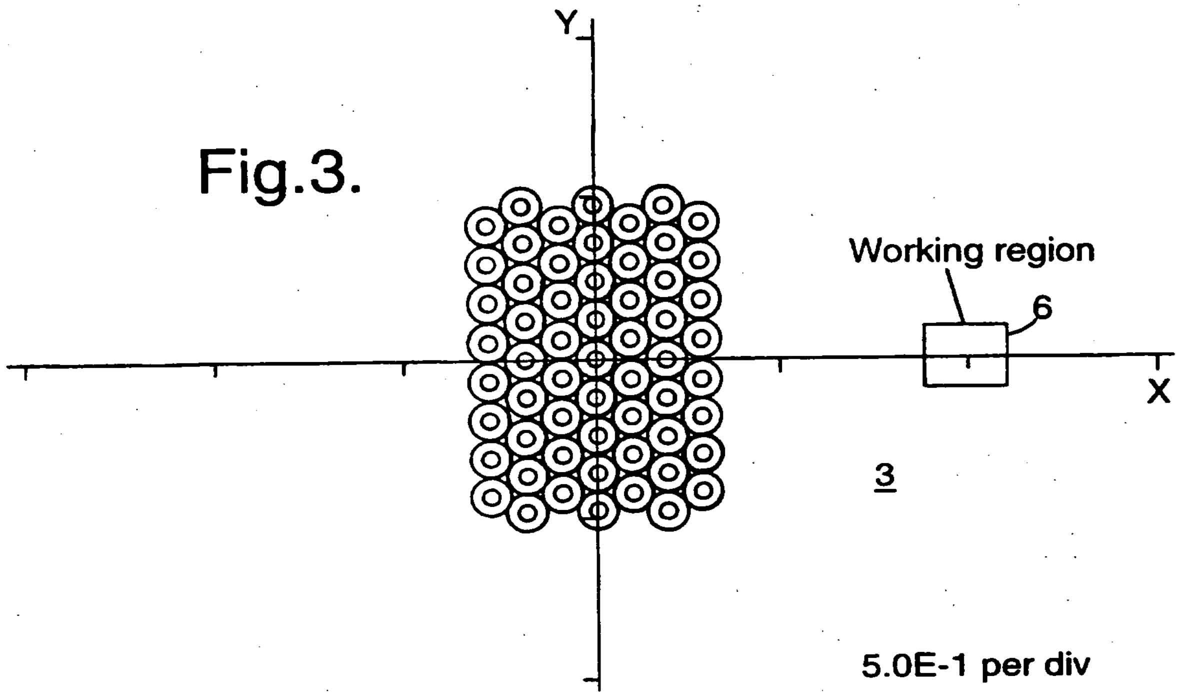

Y
X
Working region
6
3
5.0E-1 per div

Fig.4.

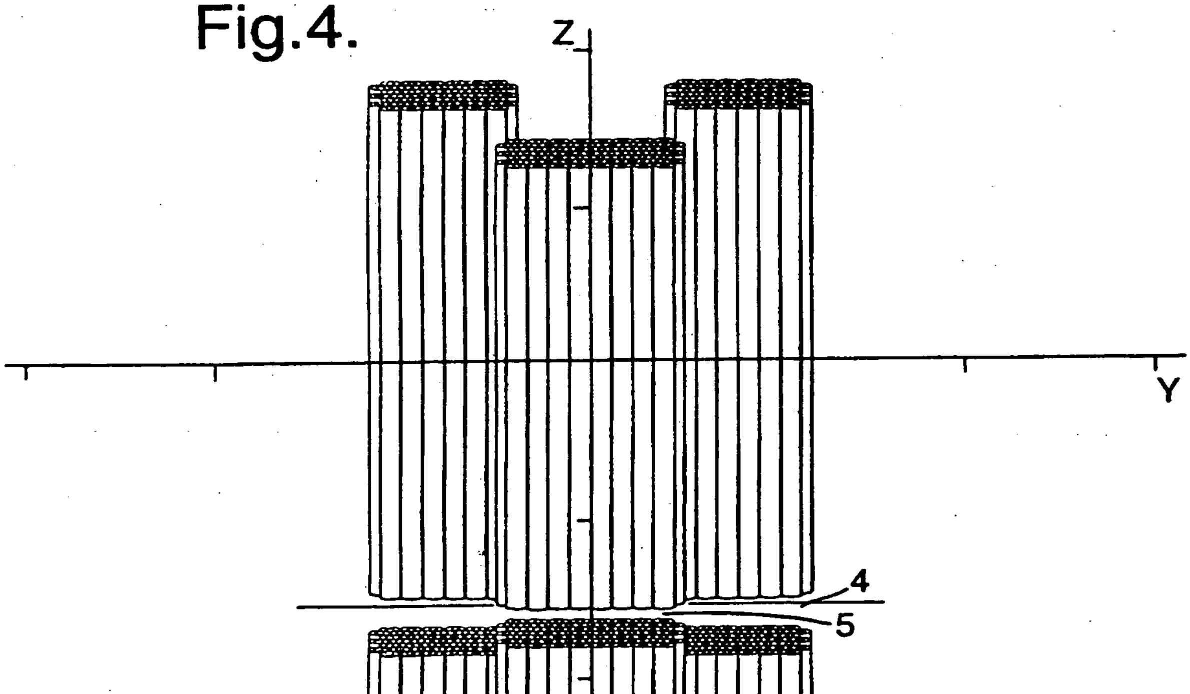

Z
Y
4
5
Origin 0.0E+000, 7.5E-001
5.0E-001 per div

Fig.5.

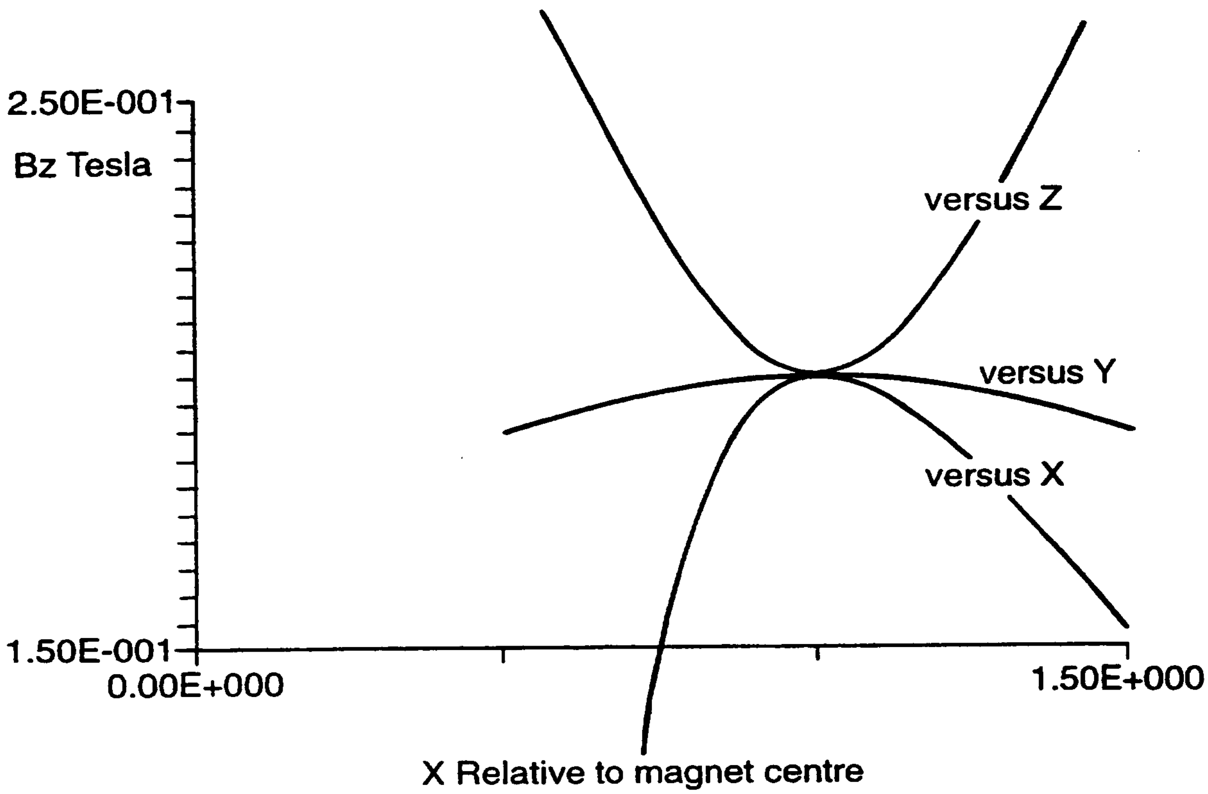
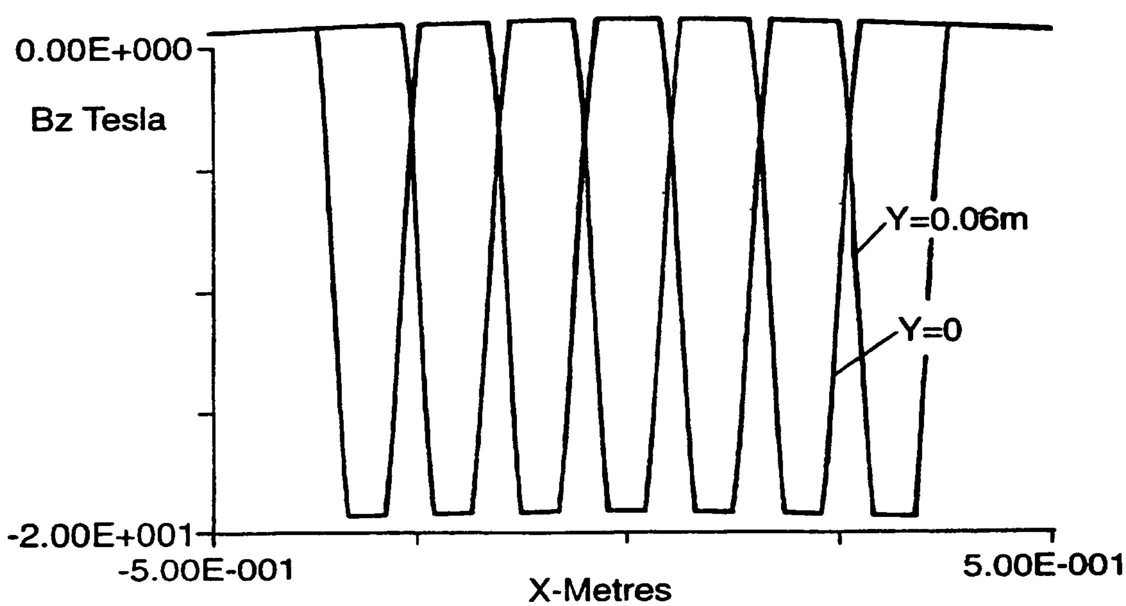



Fig.6.




Field plot through coils

Fig.7.

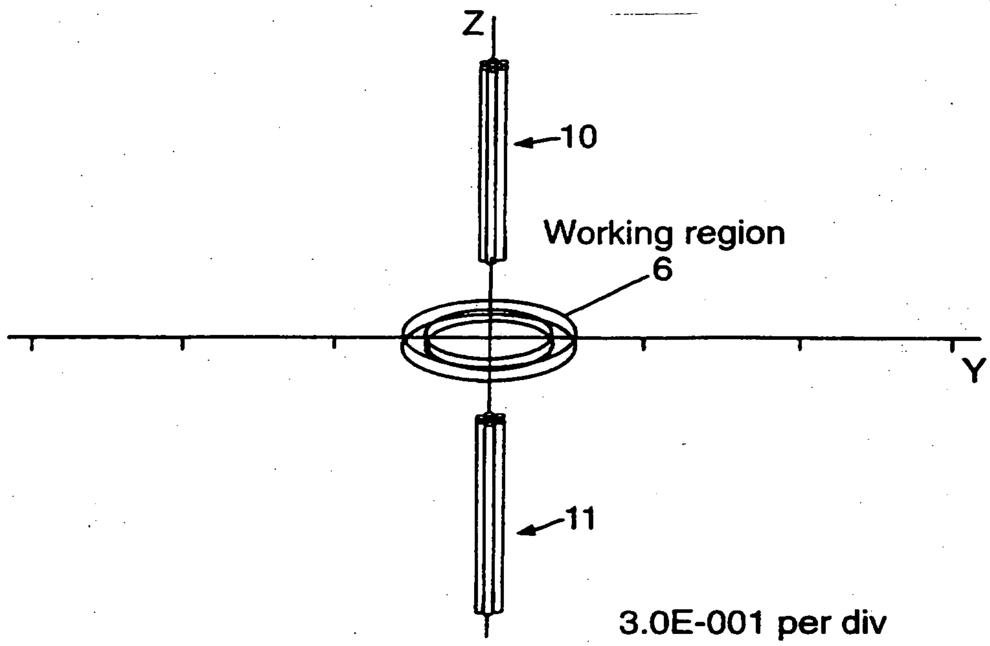

Z
10
Working region
6
Y
11
3.0E-001 per div

Fig.8.

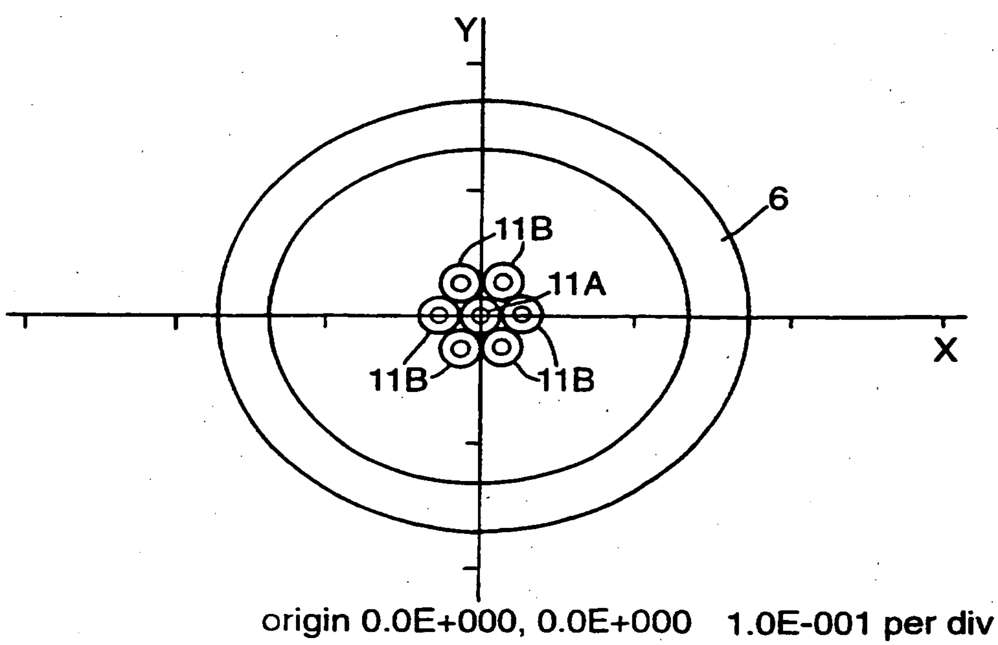
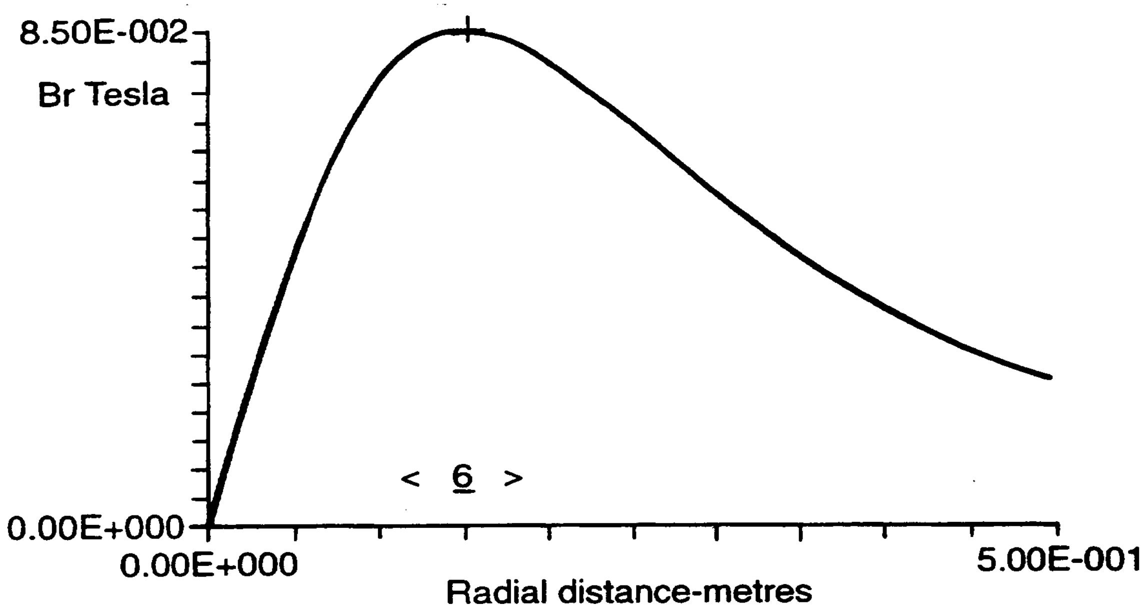
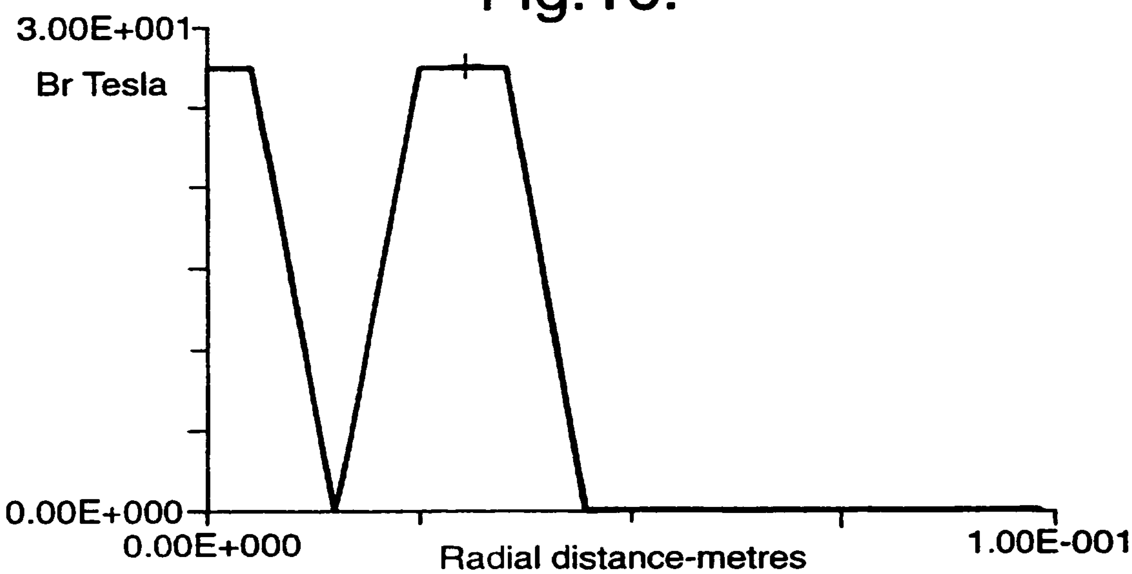

Y
6
11B
11A
X
11B
11B
origin 0.0E+000, 0.0E+000 1.0E-001 per div

Fig.9.




Seven coil-pair array
abscissa number 1 x = 1.500E-001 y = 8.540E+002

Fig.10.




Seven coil-pair system
abscissa number 1 x = 3.000E-002 y = 2.748E+001

# MAGNET ASSEMBLY

The invention relates to a magnet assembly for use in NMR apparatus.

In most forms of Nuclear Magnetic Resonance (NMR), whether spectroscopy, imaging or spatially resolved spectroscopy, the object being examined is placed within a magnet whose purpose is to produce a static magnetic field, $B_0$. The necessity of producing an intense, uniform magnetic field generally results in restricted access. This is a disadvantage when it is required to examine a very large object, or in medical applications when patient monitoring is required, or when the patient is claustrophobic.

A number of external field or "inside-out" NMR arrangements have been described, where the useful region of magnetic field is outside the magnet, allowing greater access. (Cooper R K and Jackson J A, Journal of Magnetic Resonance, 41, 400-405 (1980); Kleinberg R L, Sezginer A, Griffin D D and Fukuhara M, Journal of Magnetic Resonance, 97, 466 (1992); Eidmann G, Davelsberg R, Bluemler P and Bluemich P, Journal of Magnetic Resonance, A122, 104-109 (1996).) In general, these arrangements have suffered from low magnetic field strength and poor field uniformity. Because the sensitivity of an NMR measurement is proportional to the first or second power of the $B_0$ field (depending on the electrical conductivity of the sample and surroundings), it is desirable to have a $B_0$ field strength which is as high as possible, consistent with not affecting the properties being measured. Similarly, the usefulness of the information obtained, and the speed with which it is acquired, depend on the field uniformity. In external field NMR, the weakness of the $B_0$ field is a consequence of the remoteness of the magnet components. In conventional internal arrangements, the field uniformity is achieved through the correct distribution of the magnet components in space. In external field arrangements, the weakness of

remote components, or the weakening effect of "negative" gradient correction elements on the field intensity inhibit the achievement of good $B_0$ uniformity.

Conventional approaches to external field magnet assemblies have used axially aligned permanent magnets or axially aligned coils. The problem with permanent magnets is that in order to obtain good external field strength, an impossibly large quantity of magnetic material is required. In the case of a pair of coils, further problems arise due to the significant stresses which would develop.

In accordance with the present invention, a magnet assembly for use in NMR apparatus comprises at least two pairs of electrical current carrying coils, each coil defining an axis, whereby the coils of each pair are substantially coaxial and axially spaced apart, the axes of each coil pair being substantially parallel, and coils of each pair being positioned on opposite sides of a mid-plane, wherein, when the coils carry working currents, all the coils on one side of the mid-plane define North-South magnetic axes in the same sense and all the coils on the other side of the mid-plane define North-South magnetic axes in the same sense, the gaps between the pairs of coils being selected so that the magnetic field which is generated by each pair of coils external to the magnet assembly reaches a maximum close to or within a working region in which the magnetic field is sufficiently uniform to perform a NMR experiment.

In this new approach, we use more than one pair of axially aligned coils, typically a multiplicity of such pairs, which allows us to synthesize a desired external field configuration in which a substantially uniform magnetic field of acceptable strength and suitable for NMR is formed within the working region. Typically, all the coil pairs will generate maxima within the working region.

The invention is based on the fact that for a pair of axially aligned coils, it will be found that the Z component of field strength (where the Z axis extends in

the axial direction of the coils) goes through zero and then through a maximum in the opposite sense at some distance beyond the edge of the coils. The region within which the field reaches a maximum can be used as a region of uniformity and it should be noted that the position of this region will vary directly with the size of the gap. In some assemblies, the gap between each pair of coils will be the same. However, in general, the gap between the coils of at least two of the pairs of coils will be different. Typically, each coil pair will define a gap related to the radial distance of the coil pair from a central axis of the magnet assembly and in a preferred example, the coils of pairs further from the axis will have larger gaps than the coils of pairs nearer the axis. Varying the gap size enables coils in different lateral positions relative to the central axis of the magnet assembly all to contribute their region of uniformity within the same working region.

In the preferred arrangement, the lengths of the coils vary so as to generate magnetic fields of different strengths when carrying the working currents. This also enables account to be taken of the different positions of the pairs of coils relative to the central axis of the magnet assembly and will cause the size of the working region within which the field is uniform to extend further in a direction perpendicular to the axis.

It will be appreciated that the use of several pairs of coils allows considerable flexibility on the form of the external magnetic field. In particular, the North-South magnetic axes of individual coils can be selected as appropriate. In one preferred application, however, the North-South magnetic axes of all the coils are in the same sense. In this application, typically, a multiplicity of coil pairs will be provided, for example more than fifty.

In other preferred applications, however, such as well-logging, there is limited space for the magnet assembly and yet the working region desirably has a larger

radial dimension than that achieved in the first preferred application. In this case, the North-South magnetic axes on opposite sides of the mid-plane are in opposite senses.

Typically, the pairs of coils are closely packed (subject to the presence of support structure) so as to be nearly abutting although in other cases they could be spaced apart.

In general, low temperature superconducting materials will not be suitable since the upper critical magnetic field produced by each coil will be too weak. In the preferred applications, therefore, each coil is made from a relatively high temperature superconductor. By "relatively high temperature" we mean that the material superconducts at temperatures above 25K. Such materials include the crystalline compounds of rare-earths, strontium or barium, and copper and oxygen. Although the higher operating temperature should aid system design, the really important feature in this context is the much higher upper critical field, so giving the possibility of greater average effective magnetisation, than would be possible with permanent magnets or "low temperature" superconductors.

The definition of "uniform" must depend on the type of NMR measurement being undertaken. In the case of spectroscopy, the spectral line broadening induced by field inhomogeneities must be less than the minimum separation of the spectral lines of interest. For low-resolution spectroscopy, this might correspond to field inhomogeneity of parts per million, and for high-resolution spectroscopy to parts in $10^8$ or less. For relaxation or diffusion measurements using spin-echo techniques, requirements are less demanding and involve balancing signal increase per bandwidth increment against increased noise at larger bandwidths and signal loss due to phase cancellation. Typically, uniformities from 1 in $10^4$ to 1% are required. Similar considerations apply in NMR imaging, when the sensitivity (representing total image acquisition time)

must be traded against spatial resolution. Field uniformities in the range 1 in $10^6$ to 1 in $10^3$ are usually required.

As has already been mentioned, the invention is particularly suitable for use in well-logging applications but magnet assemblies according to the invention can be used in other applications such as spectroscopy and NMR imaging. The field of medical NMR imaging is particularly important in this case since it is easy to bring the object to be imaged into the working region.

Some examples of magnet assemblies according to the invention will now be described with reference to the accompanying drawings, in which:-

Figure 1 is a section in the Z-Y plane of a first example;

Figure 2 is a section in the Z-X plane of the first example;

Figure 3 is a plan of the first example;

Figure 4 is a more detailed, enlarged section in the Z-Y plane with the coils tilted slightly towards the viewer;

Figure 5 shows field plots across the working region generated by the example shown in Figures 1 to 4;

Figure 6 is a field plot through the array of coils shown in Figures 1 to 4;

Figure 7 is a section in the Z-Y plane of a second example;

Figure 8 is a plan of the Figure 7 example;

Figure 9 is a plot showing the external radial field profile of the example shown in Figures 7 and 8; and,

Figure 10 illustrates the magnetic field strength of the coils shown in Figures 7 and 8.

In all these examples, the material of the coils is a high temperature superconductor such as crystalline compounds of the rare-earths, strontium, barium, copper or oxygen. It will also be understood that the cryogenic apparatus needed to reduce the temperature of the

superconducting material to a superconducting level has been omitted from the drawings. In addition, when the magnet assembly is incorporated into NMR apparatus, additional apparatus will be included such as RF magnetic field generating and sensing apparatus together with additional shim magnets and the like. Once again, these have been omitted from the drawings for clarity but will be well understood by persons of ordinary skill in the art.

In the diagrams, all distances are in metres.

In the example shown in Figure 1, a multiplicity of pairs of electrical coils are arranged about a central Z axis. Each pair of coils, for example coils 1,2, is arranged with one coil 1 above a mid-plane 3 orthogonal to the Z axis and the other coil 2 below the mid-plane. The coils 1,2 are placed symmetrically about the mid-plane 3 defining a gap 4 between them. As can be seen in Figures 1 and 4, the gap 4 between the radially outer coils is larger than the gap 5 between the radially inner coils.

In the Z-X plane, the gaps between the coils increase in the negative X direction (Figure 2).

In this case, there are 118 separate coils arranged in 59 pairs and Figure 3 illustrates the configuration of pairs in plan view.

Appendix A sets out in detail the individual configurations of the coils and also the current density of each coil. The coils will be connected to a suitable current source and in series so that they all carry the same current in the same sense. This will result in the generation of North-South magnetic axes which are all in the same sense. It will be noted, however, that certain coils are longer than others and this variation in length varies with their position within the assembly. The advantage of varying the length is that this extends the region of uniformity in the Y direction.

This system produces a working region 6 (Figures 1 and 3) or volume of uniform field having a strength of 0.2T at

a distance of 1m from the centre of the magnet system. The working region 6 is only shown schematically.

Figure 5 illustrates the variation in magnetic field strength within the working region, the coil centre line being omitted since it is offset 0.5m to the left of the vertical axis. Figure 6 illustrates the variation in magnetic field strength through the array of coils shown in Figures 1 to 4 at Y=0 and Y=0.6m respectively.

From these plots, it can be seen that volumes of magnetic field within the working region, with useful strength and uniformity, can be produced at an acceptable distance from the edge of the magnet assembly.

The magnet assembly described above will require a significant volume and for certain applications such as NMR well-logging, the available volume is limited since typically the apparatus must fit within a small diameter hole. Nevertheless, the NMR signal is required to come from a region of much greater diameter.

Figure 7 illustrates an arrangement which can be used for well-logging in which seven pairs of axially aligned coils are located about the Z axis on opposite sides of the mid-plane 3. The assembly comprises seven upper coils 10 and seven lower coils 11. These will be mounted on a suitable former which can then be lowered into a drill hole. Figure 8 illustrates the location of the coils about the Z axis and it can be seen that these are closely packed with a central coil 11A (or 10A) and six coils 11B (or 10B) positioned about the central coil. Appendix B defines the configurations of the coils in the sets 10,11.

Figure 9 illustrates the external radial field profile produced by the coils 10,11 when constructed in accordance with Appendix B. The magnetic field strength of the coils in Figure 7 is shown in Figure 10. In this example, the diameter of the coil system is just 90mm leaving space for thermal insulation while the field strength in the region of interest is 0.085T, 7.5 times stronger than when using

permanent magnets. The current density in the coils is $2.2\times10^{9}$A/m$^{2}$, which leads to a peak stress of $3\times10^{8}$Pa.

In the Appendices, the parameters are defined as follows:

Element - refers to each coil by a unique "element" number.

Current - current density carried by the coil element in A/m$^{2}$.

a1 - inner winding radius.

a2 - outer winding radius.

b1 - length from nominal centre plane of assembly to one end of coil.

b2 - length from nominal centre plane of assembly to the other end.

X,Y,Z define the location of the centre of the coil in rectangular cartesian coordinates.

R,θ,Z define the centre of the coil in polar coordinates.

PHI is the angle between the coil axis and the Z axis.

PSI is the angle between the projection of the coil axis on the X,Y plane (R θ plane) and the Z axis (θ=0 direction).

## Appendix A

| element # | 1 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | 0.000E+000 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 7.500E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

| element # | 2 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | 0.000E+000 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -7.500E-002 | PSI | 0.000E+000 |

| element # | 3 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | -1.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 7.500E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

| element # | 4 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | -1.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -7.500E-002 | PSI | 0.000E+000 |

| element # | 5 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | 1.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 7.500E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

| element # | 6 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | 1.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -7.500E-002 | PSI | 0.000E+000 |

element # 7

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | -2.400E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 8

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | -2.400E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 9

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | 2.400E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 10

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | 2.400E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 11

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | -3.600E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 12

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | -3.600E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 13

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | 3.600E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 14

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | 3.600E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 15

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | -4.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 16

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | -4.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 17

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | 4.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 18

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 0.000E+000 |
| a1 | 2.500E-002 | Y | 4.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 19

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | 6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 7.500E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

element # 20

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | 6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -7.500E-002 | PSI | 0.000E+000 |

element # 21

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | -6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 7.500E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

element # 22

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | -6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -7.500E-002 | PSI | 0.000E+000 |

element # 23

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | 1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 7.500E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

element # 24

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | 1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -7.500E-002 | PSI | 0.000E+000 |

element # 25

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | -1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 7.500E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

element # 26

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | -1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -7.500E-002 | PSI | 0.000E+000 |

element # 27

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | 3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 28

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | 3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 29

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | -3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 30

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | -3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 31

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | 4.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 32

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | 4.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 33

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | -4.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 34

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 1.039E-001 |
| a1 | 2.500E-002 | Y | -4.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 35

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | 6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 7.500E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

element # 36

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | 6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -7.500E-002 | PSI | 0.000E+000 |

element # 37

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | -6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 7.500E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

element # 38

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | -6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -7.500E-002 | PSI | 0.000E+000 |

element # 39

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | 1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 7.500E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

element # 40

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | 1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -7.500E-002 | PSI | 0.000E+000 |

element # 41

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | -1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 7.500E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

element # 42

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | -1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -7.500E-002 | PSI | 0.000E+000 |

element # 43

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | 3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 44

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | 3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 45

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | -3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 46

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | -3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 47

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | 4.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 48

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | 4.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 49 | | |
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | -4.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 50 | | |
| Current | -4.622E+008 | X | -1.039E-001 |
| a1 | 2.500E-002 | Y | -4.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 51 | | |
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | 0.000E+000 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 3.000E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 52 | | |
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | 0.000E+000 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -3.000E-002 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 53 | | |
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | -1.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 3.000E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 54 | | |
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | -1.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -3.000E-002 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 55 | | |
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | 1.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 3.000E-002 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

| element # | 56 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | 1.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -3.000E-002 | PSI | 0.000E+000 |

| element # | 57 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | -2.400E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 6.000E-002 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

| element # | 58 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | -2.400E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -6.000E-002 | PSI | 0.000E+000 |

| element # | 59 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | 2.400E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 6.000E-002 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

| element # | 60 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | 2.400E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -6.000E-002 | PSI | 0.000E+000 |

| element # | 61 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | -3.600E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 6.000E-002 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

| element # | 62 | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | -3.600E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -6.000E-002 | PSI | 0.000E+000 |

element # 63

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | 3.600E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 6.000E-002 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 64

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | 3.600E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -6.000E-002 | PSI | 0.000E+000 |

element # 65

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | -4.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 6.000E-002 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 66

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | -4.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -6.000E-002 | PSI | 0.000E+000 |

element # 67

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | 4.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 6.000E-002 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 68

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 2.078E-001 |
| a1 | 2.500E-002 | Y | 4.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -6.000E-002 | PSI | 0.000E+000 |

element # 69

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | 6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 3.000E-002 | PHI | 0.000E+000 |
| b2 | 1.200E+000 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 70 | | |
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | 6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.200E+000 | PHI | 0.000E+000 |
| b2 | -3.000E-002 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 71 | | |
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | -6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 3.000E-002 | PHI | 0.000E+000 |
| b2 | 1.200E+000 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 72 | | |
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | -6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.200E+000 | PHI | 0.000E+000 |
| b2 | -3.000E-002 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 73 | | |
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | 1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 3.000E-002 | PHI | 0.000E+000 |
| b2 | 1.200E+000 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 74 | | |
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | 1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.200E+000 | PHI | 0.000E+000 |
| b2 | -3.000E-002 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 75 | | |
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | -1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 3.000E-002 | PHI | 0.000E+000 |
| b2 | 1.200E+000 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 76 | | |
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | -1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.200E+000 | PHI | 0.000E+000 |
| b2 | -3.000E-002 | PSI | 0.000E+000 |

element # 77

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | 3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 6.000E-002 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 78

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | 3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -6.000E-002 | PSI | 0.000E+000 |

element # 79

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | -3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 6.000E-002 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 80

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | -3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -6.000E-002 | PSI | 0.000E+000 |

element # 81

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | 4.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 6.000E-002 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 82

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | 4.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -6.000E-002 | PSI | 0.000E+000 |

element # 83

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | -4.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 6.000E-002 | PSI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 84 | | |
| Current | -4.622E+008 | X | 3.118E-001 |
| a1 | 2.500E-002 | Y | -4.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -6.000E-002 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 85 | | |
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | 0.000E+000 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 86 | | |
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | 0.000E+000 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 87 | | |
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | -1.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 88 | | |
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | -1.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 89 | | |
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | 1.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

| | | | |
|---|---|---|---|
| element # | 90 | | |
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | 1.200E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 91

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | -2.400E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.250E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 92

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | -2.400E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.250E-001 | PSI | 0.000E+000 |

element # 93

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | 2.400E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.250E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 94

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | 2.400E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.250E-001 | PSI | 0.000E+000 |

element # 95

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | -3.600E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.250E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 96

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | -3.600E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.600E+000 | PHI | 0.000E+000 |
| b2 | -1.250E-001 | PSI | 0.000E+000 |

element # 97

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -2.078E-001 |
| a1 | 2.500E-002 | Y | 3.600E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.250E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 98

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -2.078E-001 |
| a2 | 6.000E-002 | Y | 3.600E-001 |
| b1 | -1.600E+000 | Z | 0.000E+000 |
| b2 | -1.250E-001 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 99

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -2.078E-001 |
| a2 | 6.000E-002 | Y | -4.800E-001 |
| b1 | 1.250E-001 | Z | 0.000E+000 |
| b2 | 1.600E+000 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 100

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -2.078E-001 |
| a2 | 6.000E-002 | Y | -4.800E-001 |
| b1 | -1.600E+000 | Z | 0.000E+000 |
| b2 | -1.250E-001 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 101

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -2.078E-001 |
| a2 | 6.000E-002 | Y | 4.800E-001 |
| b1 | 1.250E-001 | Z | 0.000E+000 |
| b2 | 1.600E+000 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 102

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -2.078E-001 |
| a2 | 6.000E-002 | Y | 4.800E-001 |
| b1 | -1.600E+000 | Z | 0.000E+000 |
| b2 | -1.250E-001 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 103

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -3.118E-001 |
| a2 | 6.000E-002 | Y | 6.000E-002 |
| b1 | 1.000E-001 | Z | 0.000E+000 |
| b2 | 1.400E+000 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 104

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -3.118E-001 |
| a2 | 6.000E-002 | Y | 6.000E-002 |
| b1 | -1.400E+000 | Z | 0.000E+000 |
| b2 | -1.000E-001 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 105

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -3.118E-001 |
| a1 | 2.500E-002 | Y | -6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

element # 106

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -3.118E-001 |
| a1 | 2.500E-002 | Y | -6.000E-002 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 107

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -3.118E-001 |
| a1 | 2.500E-002 | Y | 1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

element # 108

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -3.118E-001 |
| a1 | 2.500E-002 | Y | 1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 109

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -3.118E-001 |
| a1 | 2.500E-002 | Y | -1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.000E-001 | PHI | 0.000E+000 |
| b2 | 1.400E+000 | PSI | 0.000E+000 |

element # 110

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -3.118E-001 |
| a1 | 2.500E-002 | Y | -1.800E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | -1.400E+000 | PHI | 0.000E+000 |
| b2 | -1.000E-001 | PSI | 0.000E+000 |

element # 111

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | X | -3.118E-001 |
| a1 | 2.500E-002 | Y | 3.000E-001 |
| a2 | 6.000E-002 | Z | 0.000E+000 |
| b1 | 1.250E-001 | PHI | 0.000E+000 |
| b2 | 1.600E+000 | PSI | 0.000E+000 |

element # 112

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -3.118E-001 |
| a2 | 6.000E-002 | Y | 3.000E-001 |
| b1 | -1.600E+000 | Z | 0.000E+000 |
| b2 | -1.250E-001 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 113

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -3.118E-001 |
| a2 | 6.000E-002 | Y | -3.000E-001 |
| b1 | 1.250E-001 | Z | 0.000E+000 |
| b2 | 1.600E+000 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 114

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -3.118E-001 |
| a2 | 6.000E-002 | Y | -3.000E-001 |
| b1 | -1.600E+000 | Z | 0.000E+000 |
| b2 | -1.250E-001 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 115

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -3.118E-001 |
| a2 | 6.000E-002 | Y | 4.200E-001 |
| b1 | 1.250E-001 | Z | 0.000E+000 |
| b2 | 1.600E+000 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 116

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -3.118E-001 |
| a2 | 6.000E-002 | Y | 4.200E-001 |
| b1 | -1.600E+000 | Z | 0.000E+000 |
| b2 | -1.250E-001 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 117

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -3.118E-001 |
| a2 | 6.000E-002 | Y | -4.200E-001 |
| b1 | 1.250E-001 | Z | 0.000E+000 |
| b2 | 1.600E+000 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

element # 118

| | | | |
|---|---|---|---|
| Current | -4.622E+008 | | |
| a1 | 2.500E-002 | X | -3.118E-001 |
| a2 | 6.000E-002 | Y | -4.200E-001 |
| b1 | -1.600E+000 | Z | 0.000E+000 |
| b2 | -1.250E-001 | PHI | 0.000E+000 |
| | | PSI | 0.000E+000 |

## Appendix B

element # 1

| | | | |
|---|---|---|---|
| Current | 2.200E+009 | R | 0.000E+000 |
| a1 | 5.000E-003 | θ | 0.000E+000 |
| a2 | 1.500E-002 | Z | 4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 2

| | | | |
|---|---|---|---|
| Current | -2.200E+009 | R | 0.000E+000 |
| a1 | 5.000E-003 | θ | 0.000E+000 |
| a2 | 1.500E-002 | Z | -4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 3

| | | | |
|---|---|---|---|
| Current | 2.200E+009 | R | 3.000E-002 |
| a1 | 5.000E-003 | θ | 0.000E+000 |
| a2 | 1.500E-002 | Z | 4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 4

| | | | |
|---|---|---|---|
| Current | -2.200E+009 | R | 3.000E-002 |
| a1 | 5.000E-003 | θ | 0.000E+000 |
| a2 | 1.500E-002 | Z | -4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 5

| | | | |
|---|---|---|---|
| Current | 2.200E+009 | R | 3.000E-002 |
| a1 | 5.000E-003 | θ | 6.000E+001 |
| a2 | 1.500E-002 | Z | 4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 6

| | | | |
|---|---|---|---|
| Current | -2.200E+009 | R | 3.000E-002 |
| a1 | 5.000E-003 | θ | 6.000E+001 |
| a2 | 1.500E-002 | Z | -4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 7

| | | | |
|---|---|---|---|
| Current | 2.200E+009 | R | 3.000E-002 |
| a1 | 5.000E-003 | θ | 1.200E+002 |
| a2 | 1.500E-002 | Z | 4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 8

| | | | |
|---|---|---|---|
| Current | -2.200E+009 | R | 3.000E-002 |
| a1 | 5.000E-003 | θ | 1.200E+002 |
| a2 | 1.500E-002 | Z | -4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 9

| | | | |
|---|---|---|---|
| Current | 2.200E+009 | R | 3.000E-002 |
| a1 | 5.000E-003 | θ | -1.800E+002 |
| a2 | 1.500E-002 | Z | 4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 10

| | | | |
|---|---|---|---|
| Current | -2.200E+009 | R | 3.000E-002 |
| a1 | 5.000E-003 | θ | -1.800E+002 |
| a2 | 1.500E-002 | Z | -4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 11

| | | | |
|---|---|---|---|
| Current | 2.200E+009 | R | 3.000E-002 |
| a1 | 5.000E-003 | θ | -1.200E+002 |
| a2 | 1.500E-002 | Z | 4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 12

| | | | |
|---|---|---|---|
| Current | -2.200E+009 | R | 3.000E-002 |
| a1 | 5.000E-003 | θ | -1.200E+002 |
| a2 | 1.500E-002 | Z | -4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 13

| | | | |
|---|---|---|---|
| Current | 2.200E+009 | R | 3.000E-002 |
| a1 | 5.000E-003 | θ | -6.000E+001 |
| a2 | 1.500E-002 | Z | 4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

element # 14

| | | | |
|---|---|---|---|
| Current | -2.200E+009 | R | 3.000E-002 |
| a1 | 5.000E-003 | θ | -6.000E+001 |
| a2 | 1.500E-002 | Z | -4.600E-001 |
| b1 | -2.500E-001 | PHI | 0.000E+000 |
| b2 | 2.500E-001 | PSI | 0.000E+000 |

## CLAIMS

1. A magnet assembly for use in NMR apparatus, the assembly comprising at least two pairs of electrical current carrying coils, each coil defining an axis, whereby the coils of each pair are substantially coaxial and axially spaced apart, the axes of each coil pair being substantially parallel, and coils of each pair being positioned on opposite sides of a mid-plane, wherein, when the coils carry working currents, all the coils on one side of the mid-plane define North-South magnetic axes in the same sense and all the coils on the other side of the mid-plane define North-South magnetic axes in the same sense, the gaps between the pairs of coils being selected so that the magnetic field which is generated by each pair of coils external to the magnet assembly reaches a maximum close to or within a working region in which the magnetic field is sufficiently uniform to perform a NMR experiment.

2. An assembly according to claim 1, wherein the gaps between the coils of at least two of the pairs differ.

3. An assembly according to claim 2, wherein the gap between the coils of a pair of coils nearer the working region is greater than the gap between the coils of a pair of coils further from the working region.

4. An assembly according to any of the preceding claims, wherein the lengths of the coils vary so as to generate magnetic fields of different strengths when carrying the working currents.

5. An assembly according to any of the preceding claims, wherein the North-South magnetic axes of the coils on opposite sides of the mid-plane are in the same sense.

6. An assembly according to any of claims 1 to 4, wherein the North-South magnetic axes on opposite sides of the mid-plane are in opposite senses.

7. An assembly according to any of the preceding claims, wherein the pairs of coils are closely packed.

8. An assembly according to any of the preceding claims, wherein there are at least fifty pairs of coils.

9. An assembly according to any of the preceding claims, wherein each coil is made from superconducting material.

10. An assembly according to claim 9, wherein the material superconducts at a relatively high temperature.

11. A magnet assembly substantially as hereinbefore described with reference to any of the examples shown in the accompanying drawings.

12. NMR apparatus including a magnet assembly according to any of the preceding claims; and an rf magnetic field generating and receiving assembly for carrying out an NMR experiment in the working region.

13. Well logging apparatus according to claim 12.

The Patent Office

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| | | | |
|---|---|---|---|
| **Application No:** | GB 9724832.2 | **Examiner:** | K. Sylvan |
| **Claims searched:** | 1-13 | **Date of search:** | 26 February 1998 |

## Patents Act 1977
## Search Report under Section 17

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): G1N (NG38,NG38A,NGWL)

Int Cl (Ed.6): G01R (33/38,33/381,33/3815) G01V (3/14,3/32) H01F (6/00)

Other: Online: WPI,INSPEC,JAPIO

**Documents considered to be relevant:**

| Category | Identity of document and relevant passage | | Relevant to claims |
|---|---|---|---|
| A | US5008624 | Toshiba. See figures 4 and 10, column 4 lines 27-36, and column 5 lines 17-35. | - |
| A | US4985679 | Oxford Magnet. See gaps between 9,10 and 11 in figure 4A. | - |

| | | | |
|---|---|---|---|
| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art. |
| Y | Document indicating lack of inventive step if combined with one or more other documents of same category. | P | Document published on or after the declared priority date but before the filing date of this invention. |
| | | E | Patent document published on or after, but with priority date earlier than, the filing date of this application. |
| & | Member of the same patent family | | |